The State of Magnetars

Chryssa Kouveliotou (NASA's MSFC)

Magnetars are magnetically powered NS

- ~26 sources to date – seven in 2008-2014 – All but two (LMC, SMC) are MW sources

- Discovered in X/γ-rays/radio; radio, optical and IR observations - Short, soft repeated bursts

- $P = [2\text{-}11]$ s, $\dot{P} \sim [10^{-11}\text{-}\ 10^{-13}]$s/s

- $\tau_{spindown}(P/2\dot{P})$= 2-220 kyrs

- $B\sim[1\text{-}10]\times10^{14}$ G (mean surface dipole field: $3.2\times10^{19}\sqrt{P\dot{P}}$) - **BUT:** SGRs J185246.6+003317, $B< 4.1\times10^{13}$ G; 0418+5729, $B=6.2\times10^{12}$ G; 1822.3-1606, $B\sim2.0\times10^{13}$ G

- Luminosities range from $L\sim10^{32\text{–}36}$ erg/s

- No evidence for binarity

The first signs of a new population

A flaring x-ray pulsar in Dorado

E. P. Mazets, S. V. Golenetskii, V. N. Il'inskii, V. N. Panov, R. L. Aptekar',
Yu. A. Gur'yan, I. A. Sokolov, Z. Ya. Sokolova, and T. V. Kharitonova

Ioffe Physics and Technology Institute, Academy of Sciences of the USSR, Leningrad

(Submitted May 11, 1979)

Pis'ma Astron. Zh. **5**, 307–312 (July 1979)

Unusual γ-ray bursts were recorded in March 1979 by the Cone experiment on the Venera 11 and Venera 12 space probes. Analysis indicates that the bursts emanate from a flaring x-ray pulsar in the constellation Dorado.

PACS numbers: 97.60.Gb, 98.70.Qy

On 1979 March 5 the interplanetary space probes Venera 11 and Venera 12 recorded a very strong γ-ray burst, which no doubt was also observed by many other instruments operating in space at that time. This event differs sharply in its properties from all the γ-ray bursts we have detected previously,[1] and it is of outstanding interest.

Figure 1 displays the time profile of the initial phase of the March 5 burst, as recorded by the Cone experiment[1] in the 50–150 keV energy window over a 2-sec in-

The energy spectra further indicate that the March 5 event differed significantly from bursts of γ rays. During the stage following the initial pulse, the photon spectrum was more similar in form to the spectra of the continuously operating x-ray sources that belong to binary systems (such as Cygnus X-1) than it was to the much harder spectra of γ-ray bursts. To an adequate approximation it may be represented by an expression of the form $E^{-1} \cdot \exp(-E/kt)$ for a temperature $kT = 30$ keV. The spectrum measured during the first 4 sec has a harder tail, which is presumably associated with the radiation of the initial

NS populations comprising Magnetars

Soft Gamma Repeaters (SGRs)

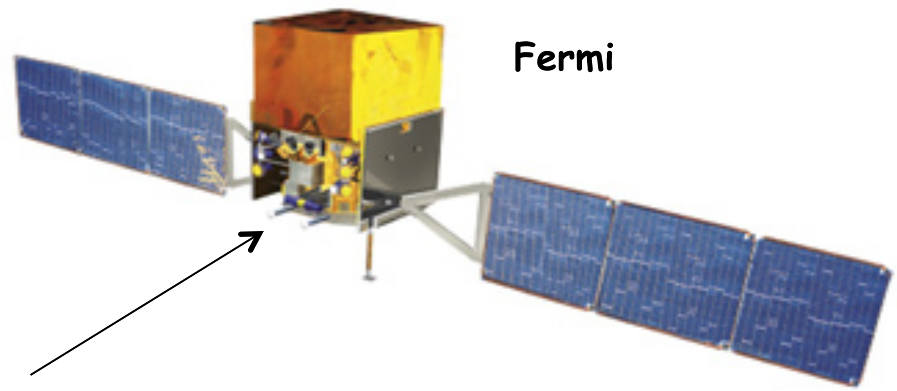
Anomalous X-ray Pulsars (AXPs)

Dim Isolated Neutron Stars (DINs)

Compact Central X-ray Objects (CCOs)

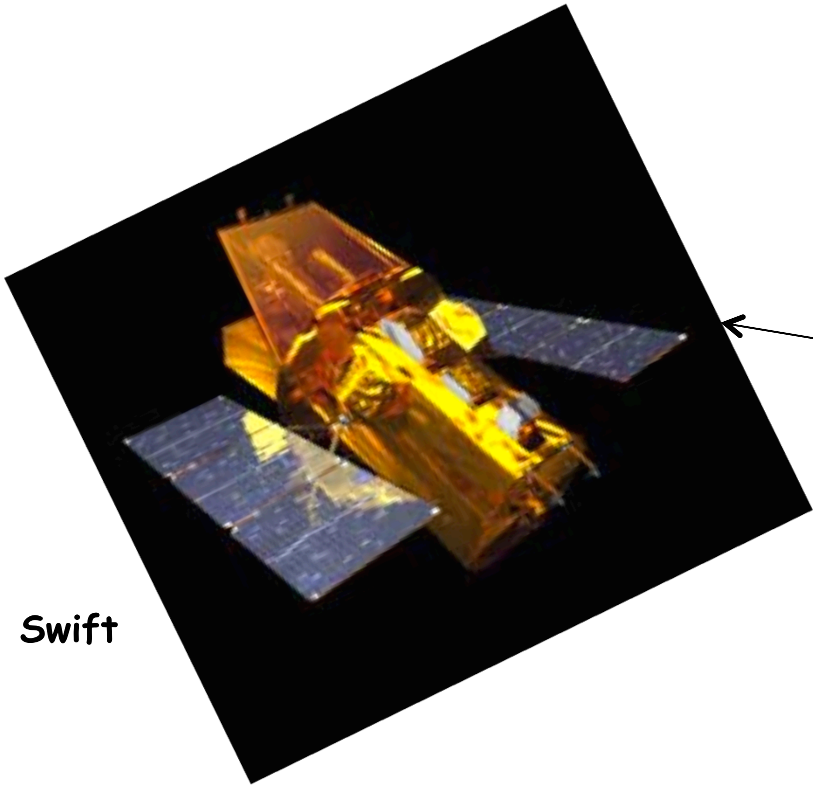
Rotation Powered Pulsars (PSRs J1846–0258 & J1622-4950)

Magnetar detection missions

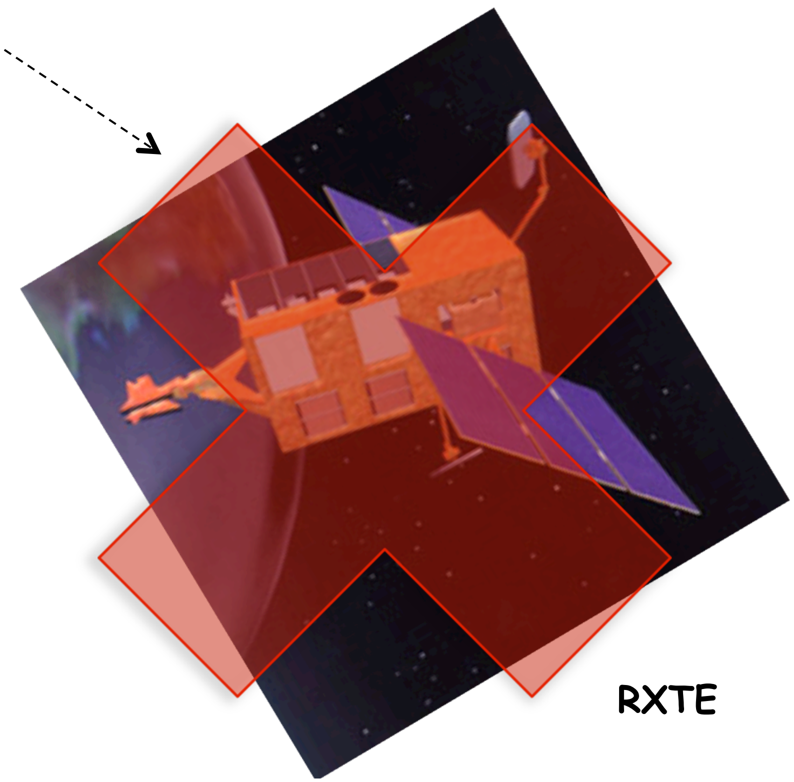


Fermi

IPN

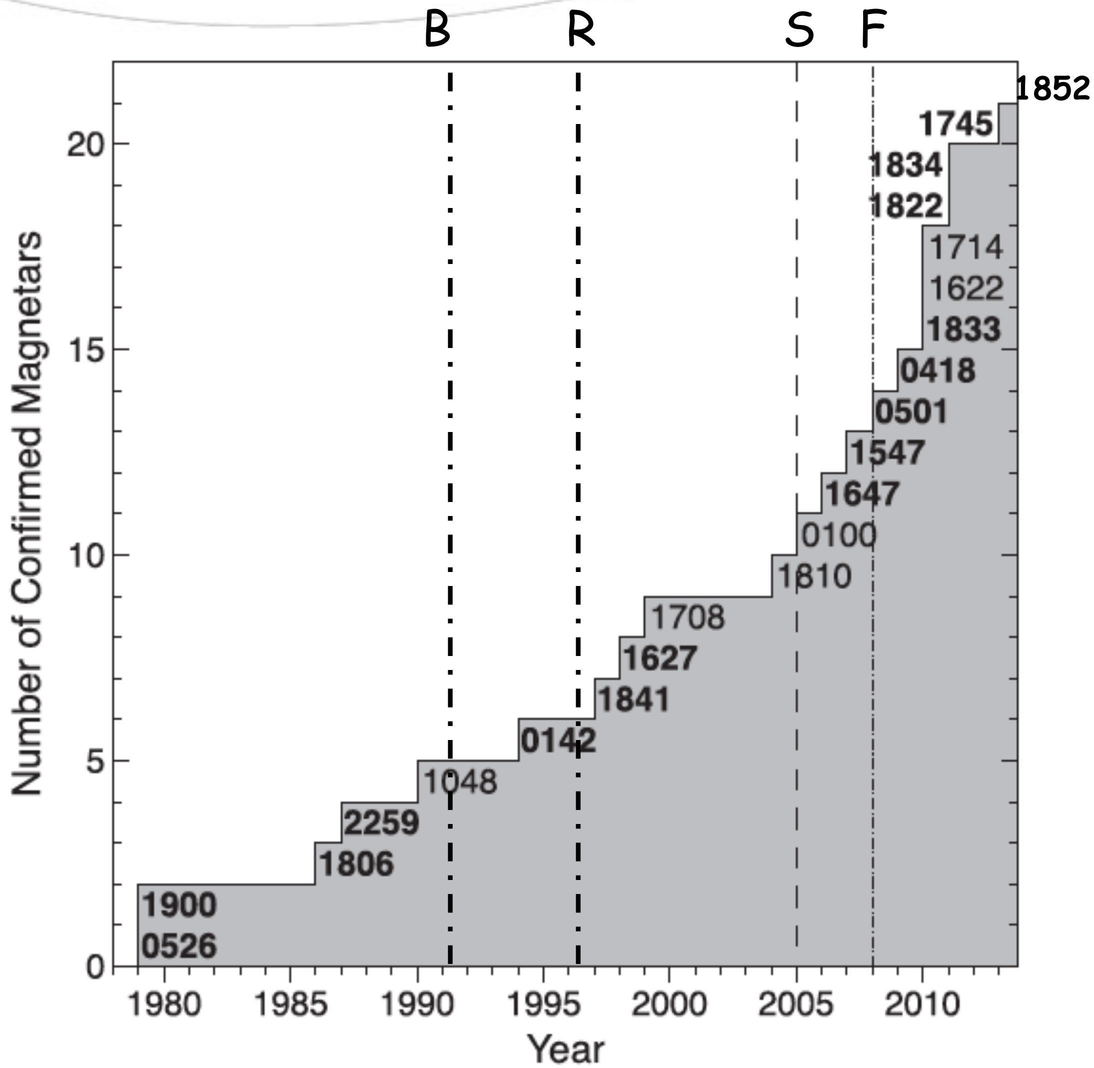


Swift



RXTE

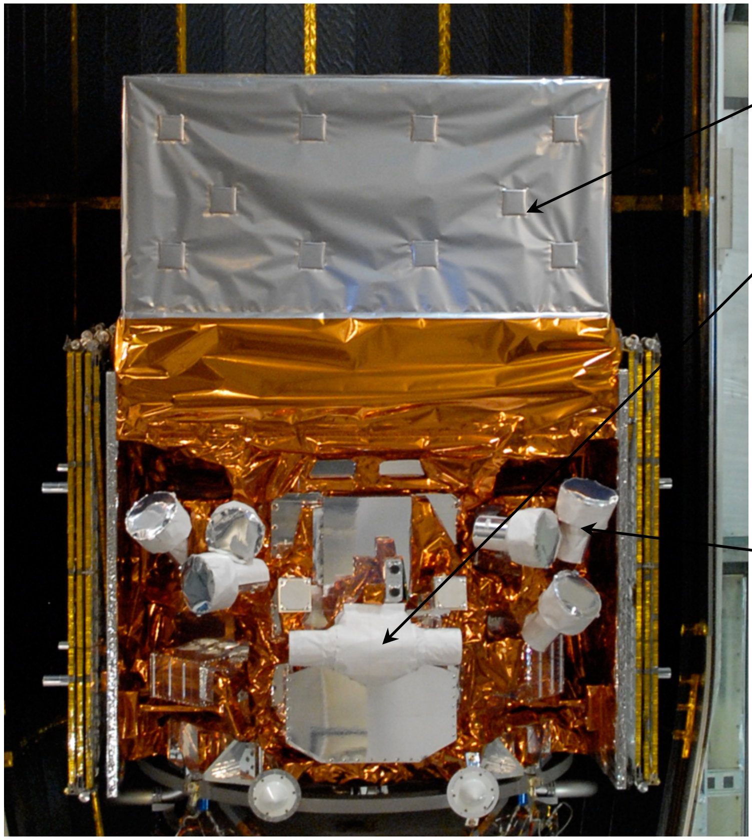
Magnetar detection rates



Olausen & Kaspi, ApJ 2014

The Fermi/Gamma-ray Burst Monitor

- 4 x 3 NaI Detectors with different orientations.
- 2 x 1 BGO Detector either side of spacecraft.
- View entire sky while maximizing sensitivity to events seen in common with the LAT



The Large Area Telescope (LAT)

GBM BGO detector.
200 keV -- 40 MeV
126 cm^2, 12.7 cm
Triggering, Spectroscopy
Bridges gap between NaI and LAT.

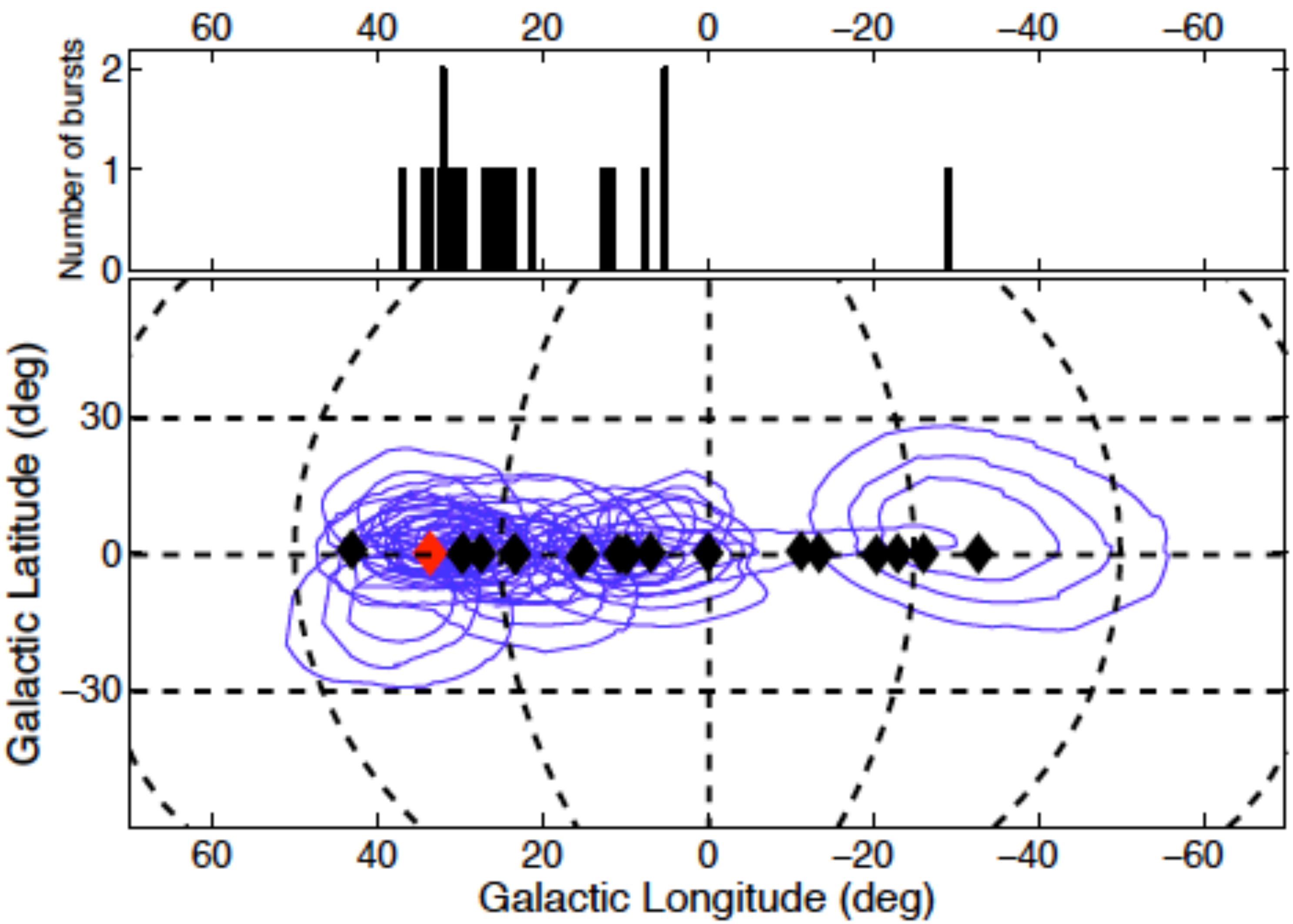
GBM NaI detector.
8 keV -- 1000 keV
126 cm^2, 1.27 cm
Triggering, Localization, Spectroscopy.

GBM 5-yr Magnetar Burst Catalog

Collazzi et al., 2014

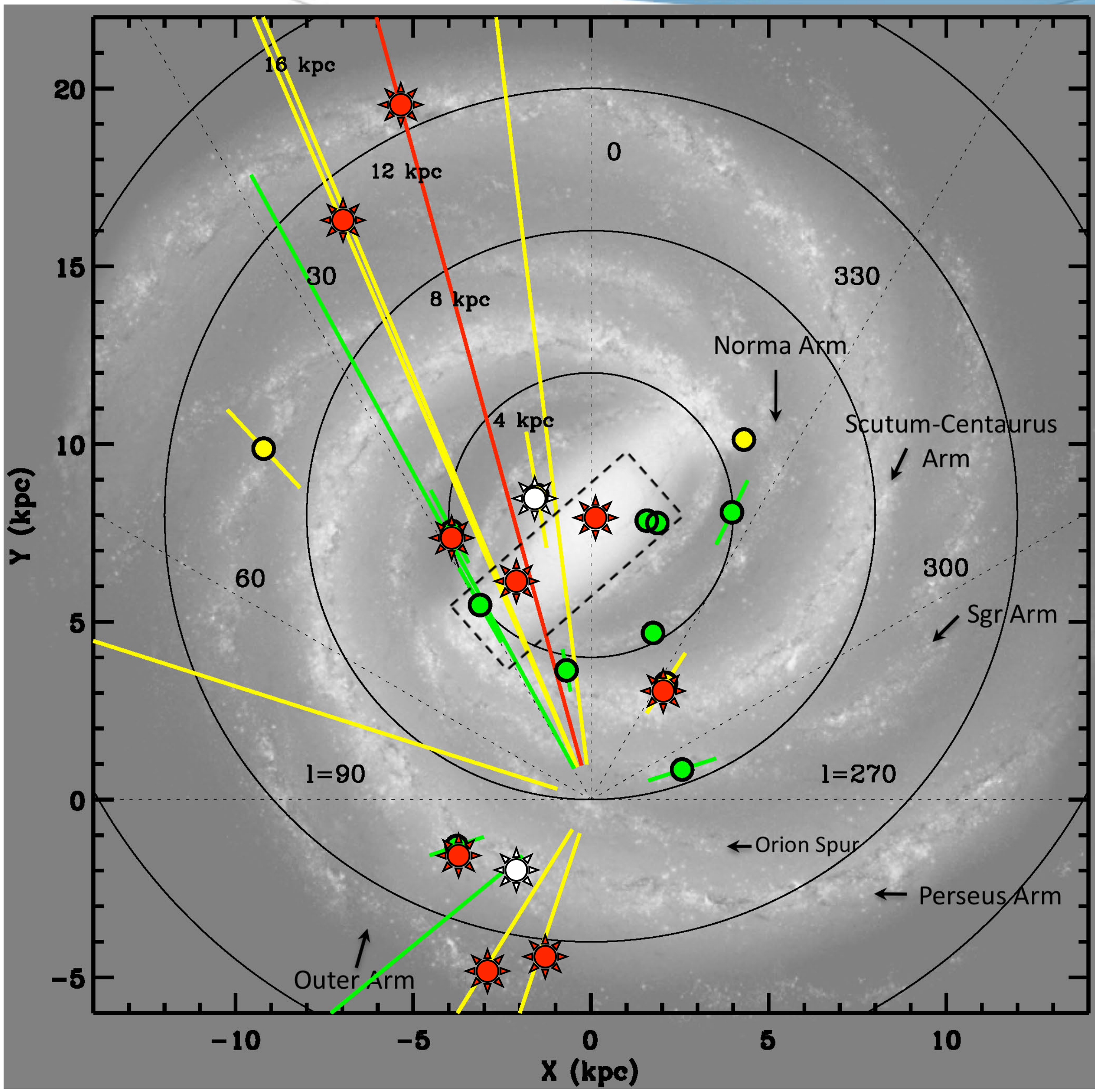
Magnetar	Active Period	Triggers	Comments
SGR J0501+4516	Aug/Sep 2008	26	**New source** at Perseus arm
SGR J1550-5418	Oct 2008 Jan/Feb 2009 Mar/Apr 2009 June 2013	7 117/331+ 14 1	Known source – first burst active episodes
SGR J0418+5729	June 2009	2	**New source** at Perseus arm
SGR 1806-20	Mar 2010	1	Old source - reactivation
AXP 1841-045	Feb 2011 June/July 2011	3 4	Known source – first burst active episodes
SGR 1822-1606	July 2011	1	**New source** in galactic center region
AXP 4U0142+61	July 2011	1	Old source - reactivation
1E 2259+586	April 2012	1	Old source - reactivation
Unconfirmed Origin	2008-2013	21	Multiple error boxes include new source 3XMM J185246.6+003317

Unknown source locations



Collazzi et al. 2014

Magnetar Distribution in our Galaxy



NEW: GBM Bursts detected since Fermi launch SYNERGY: Swift-Fermi-RXTE-IPN

Old source reactivation

SGRs

AXPs

CRADLE

Kouveliotou et al. 2011

The magnetar conjecture

The neutron star is powered by its super strong B-field = 10^{14-15} G. To create such fields requires the collapse of a fast rotating star (1-3 ms) with very high convection rates (magnetic Reynolds number ~10^{17}). Ideal efficiency can generate ~ 10^{16}G (Duncan and Thompson 1992, 1993).

However: The magnetic energy has to be less than the gravitational binding energy of the neutron star (Lai 2001) providing an upper limit of:

$$\frac{4\pi R^3}{3}\left(\frac{B^2}{8\pi}\right) \lesssim \frac{GM^2}{R}.$$

$$B \lesssim 10^{18}\left(\frac{M}{1.4\ M_\odot}\right)\left(\frac{R}{10\ \mathrm{km}}\right)^{-2}\ \mathrm{G}.$$

Magnetar States

- Quiescent
- Active
    - Several 100s of bursts (storms) – 4 sources
    - Giant Flares (3 sources one each)
    - Few 10s of bursts (3 sources)
    - <10 bursts (10 sources)
    - No bursts (4 sources)

Quiescent Emission Properties

Magnetar Timing Properties

From the **quiescent** pulsed X-ray emission we can calculate:

The minimum surface dipole field in vacuum :

$B = 3.2 \times 10^{19} (P\dot{P})^{1/2}$ G (minimum magnetic field strength in vacuum);

The spindown luminosity:

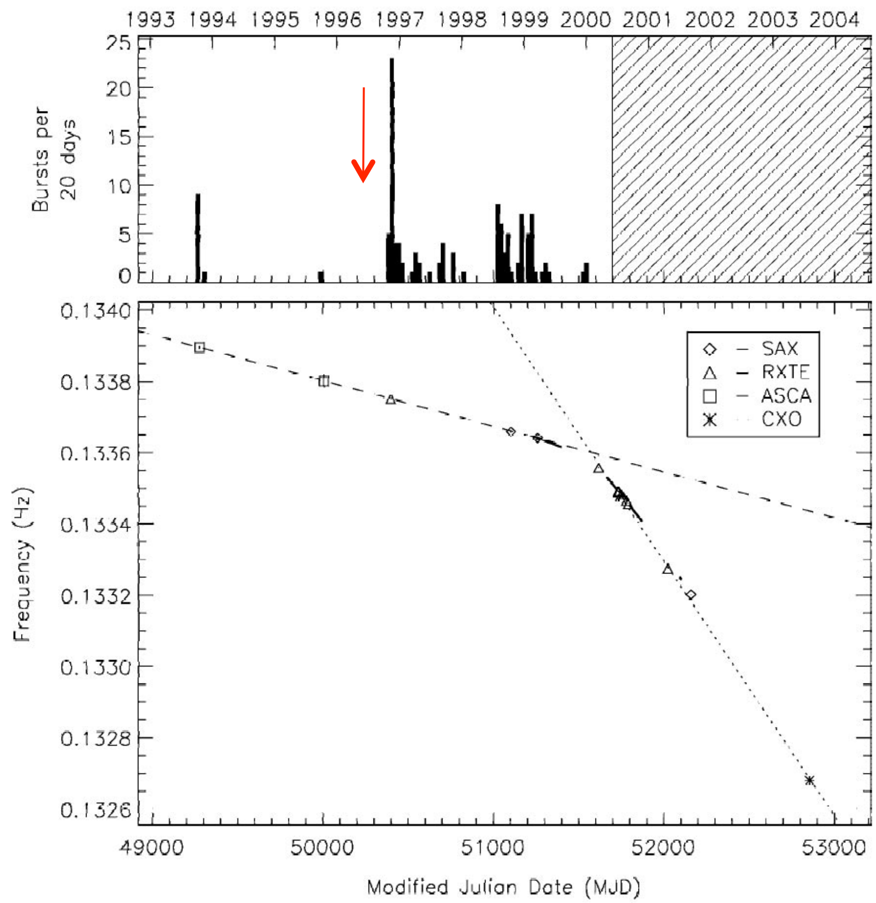
$\dot{E} = 4\pi 2I \dot{P}/P^3$ ($I = 10^{45}$ g cm^2);

The characteristic age:

$\tau_c = P/ 2\dot{P}$

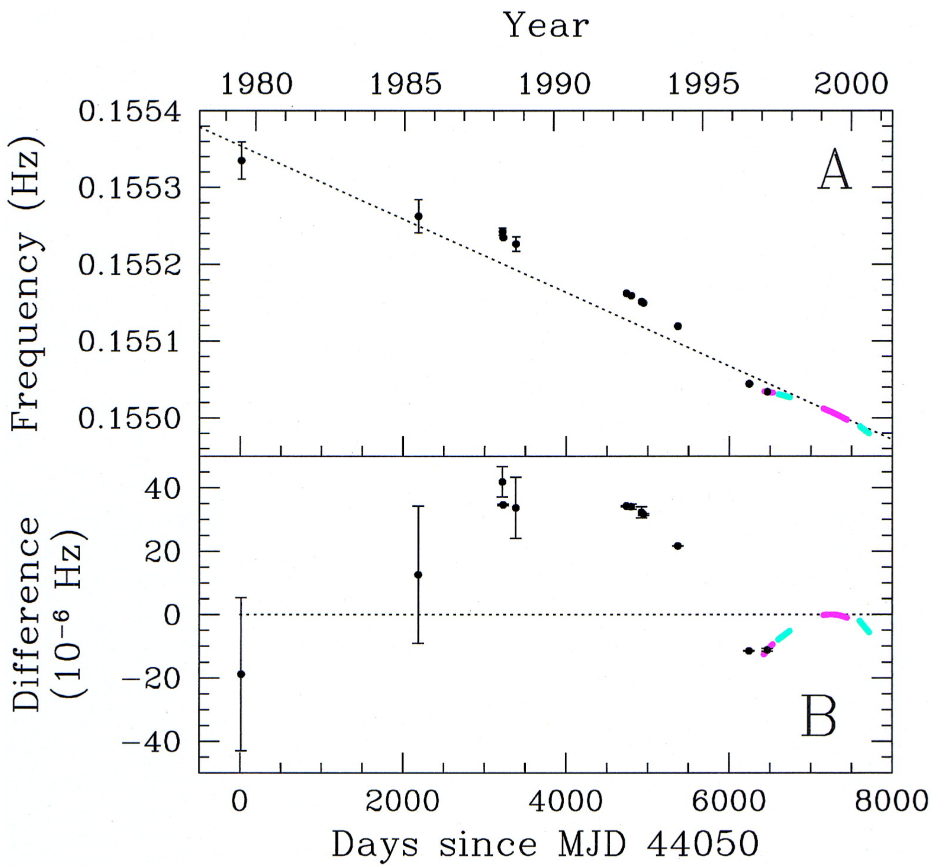
Magnetar Timing Properties

SGR 1806-20



Woods et al 2002

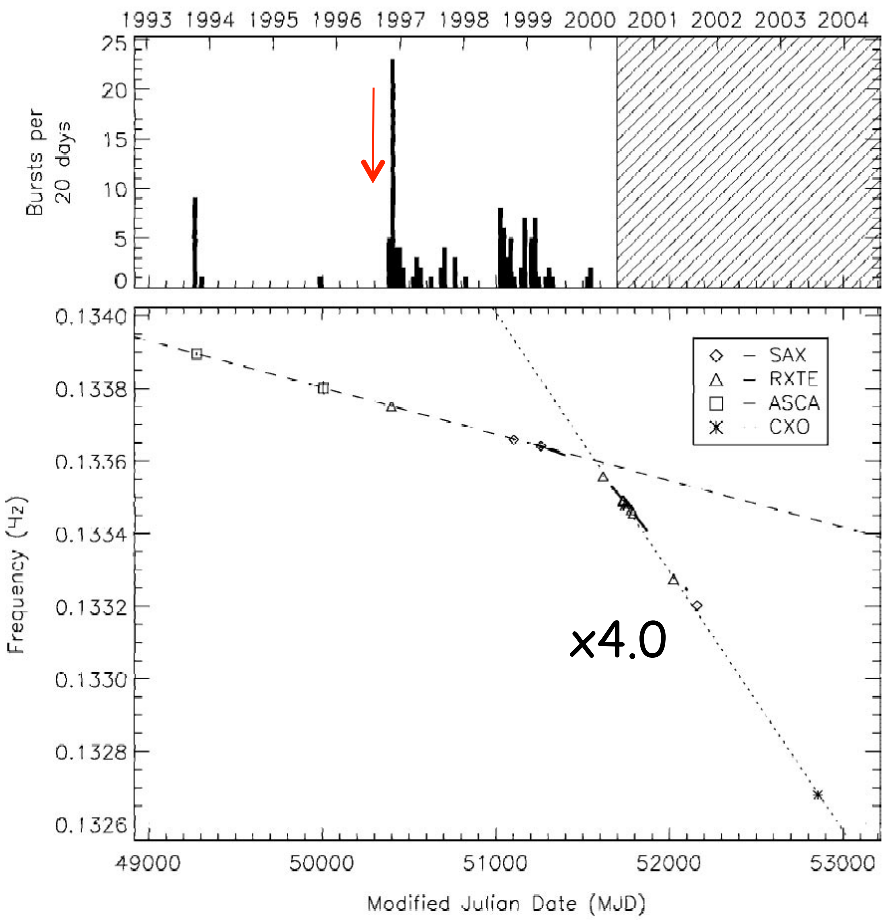
AXP 1E 1048.1-5937



Kaspi et al. 2001

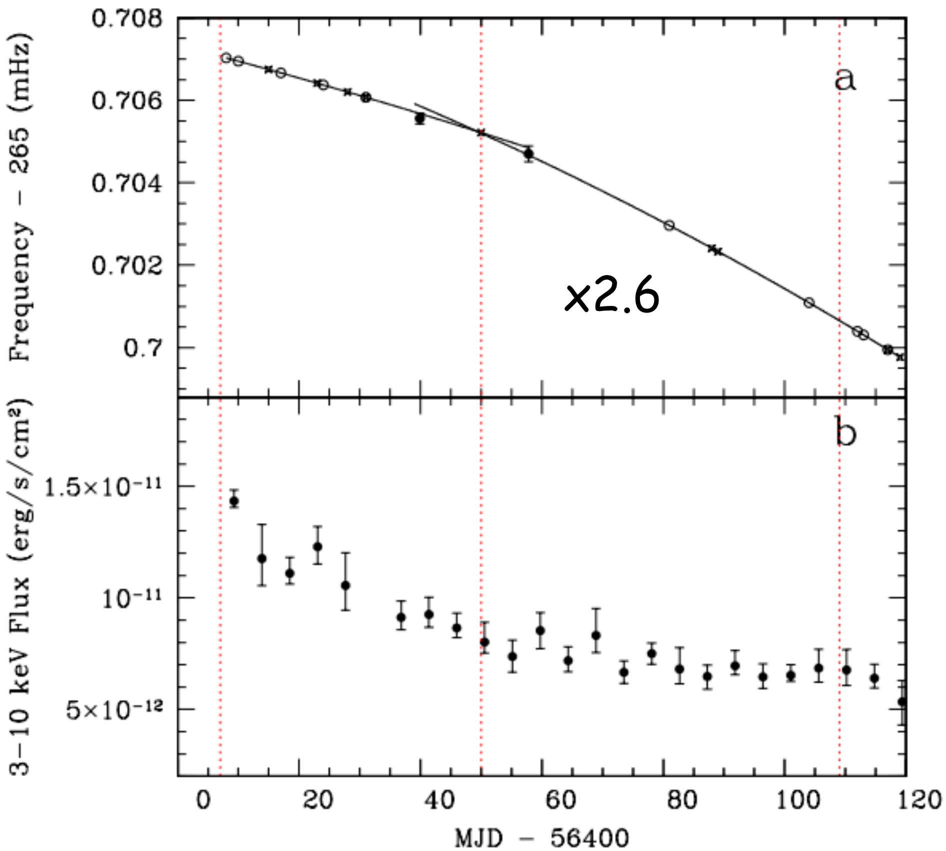
Magnetar Timing Properties

SGR 1806-20



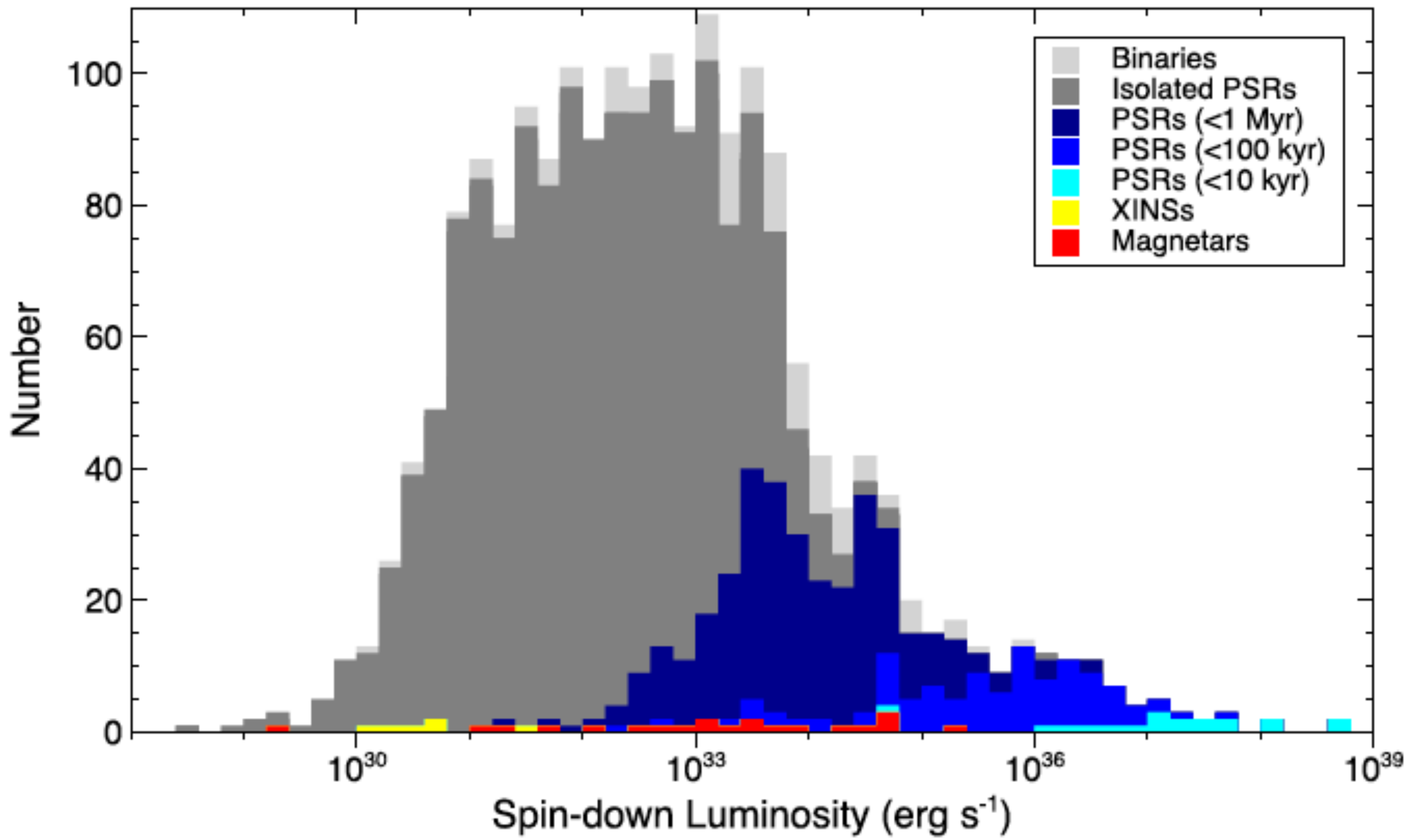
Woods et al 2002

SGR J1745-2900



Kaspi et al. 2014

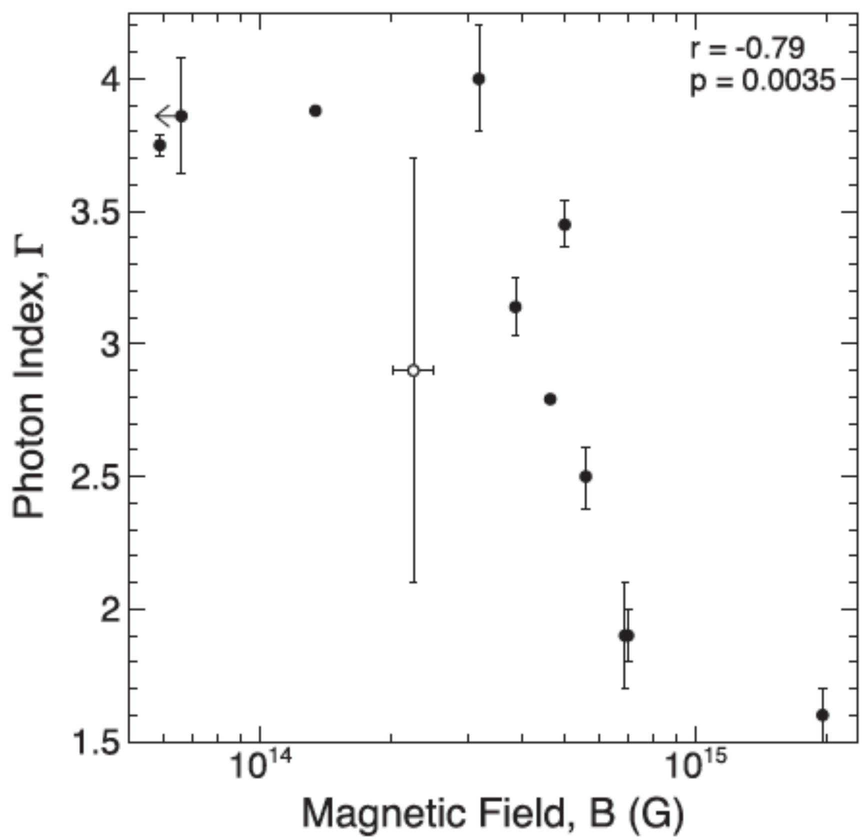
Spindown Luminosities

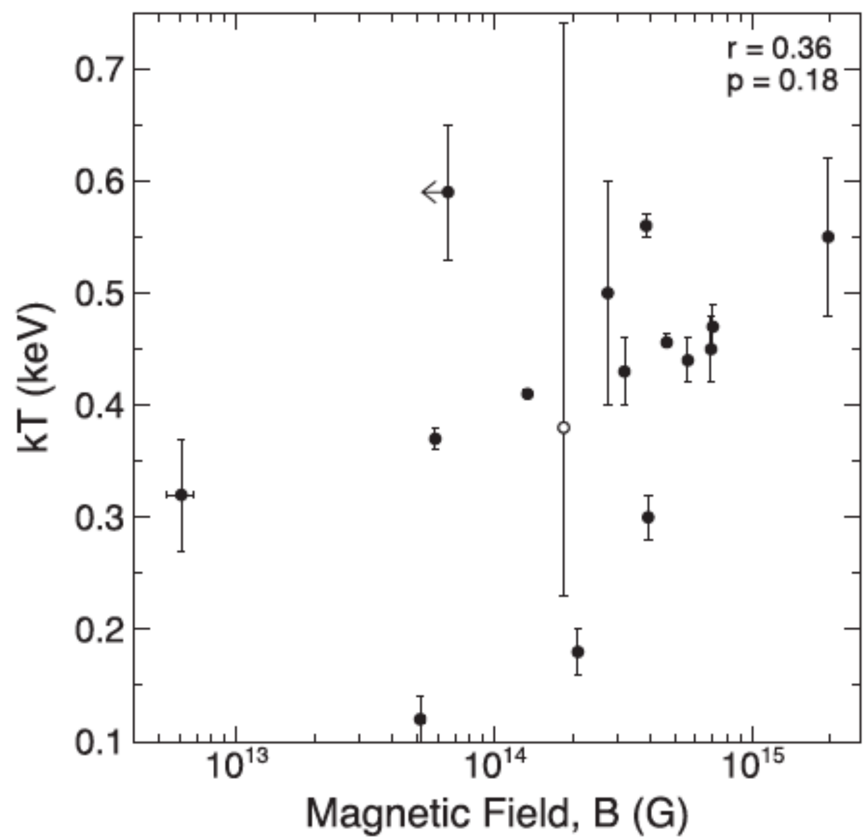


Olausen & Kaspi, ApJ 2014

Magnetar Spectral Properties

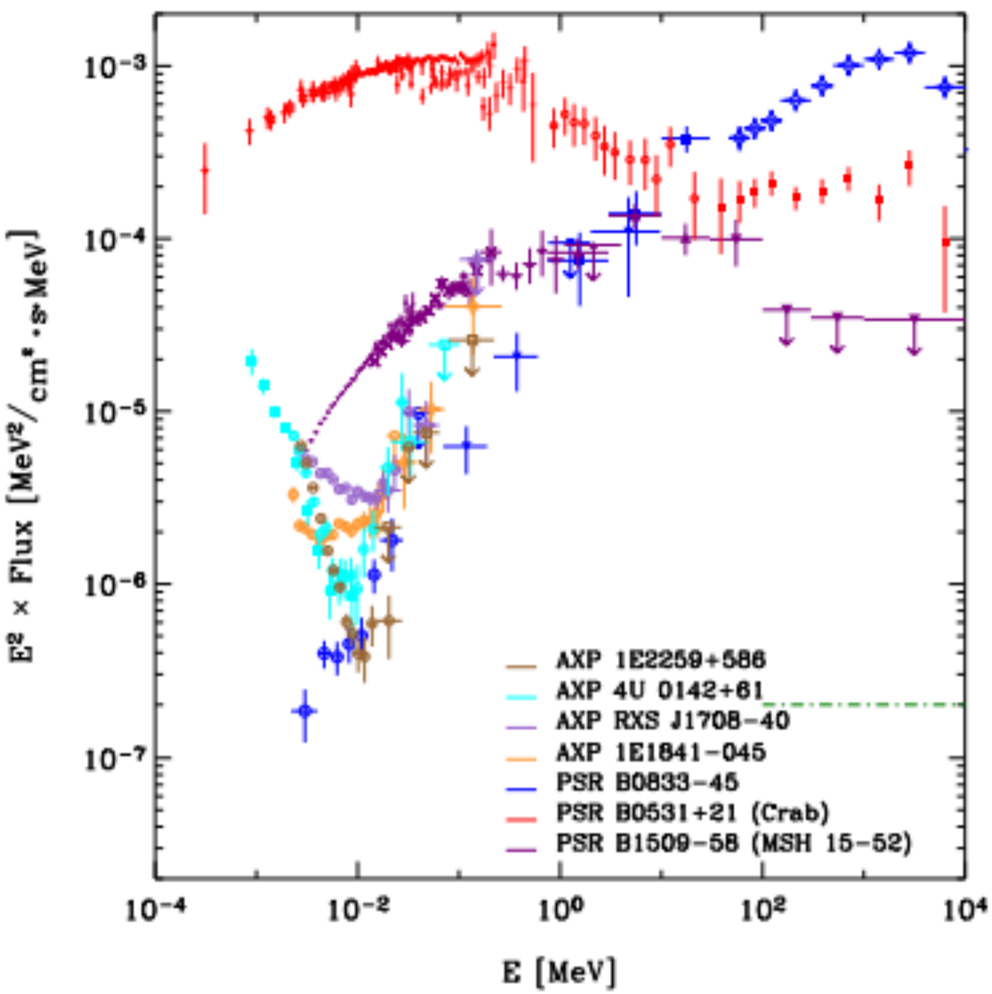
Most spectra are best fit with an absorbed PL + BB



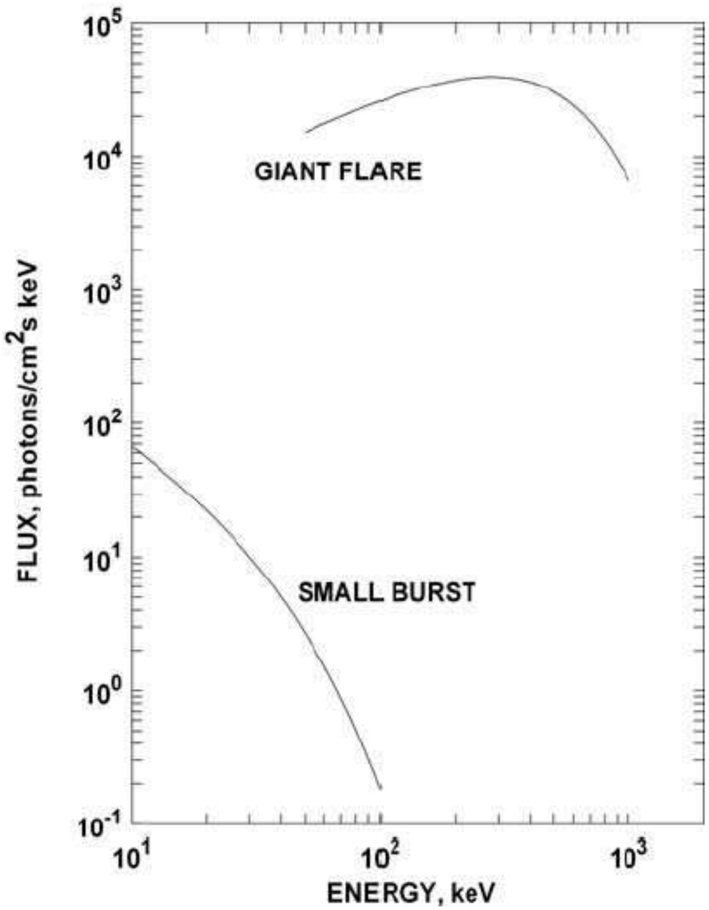


Olausen & Kaspi, ApJ 2014

Pulsed Emission Spectra

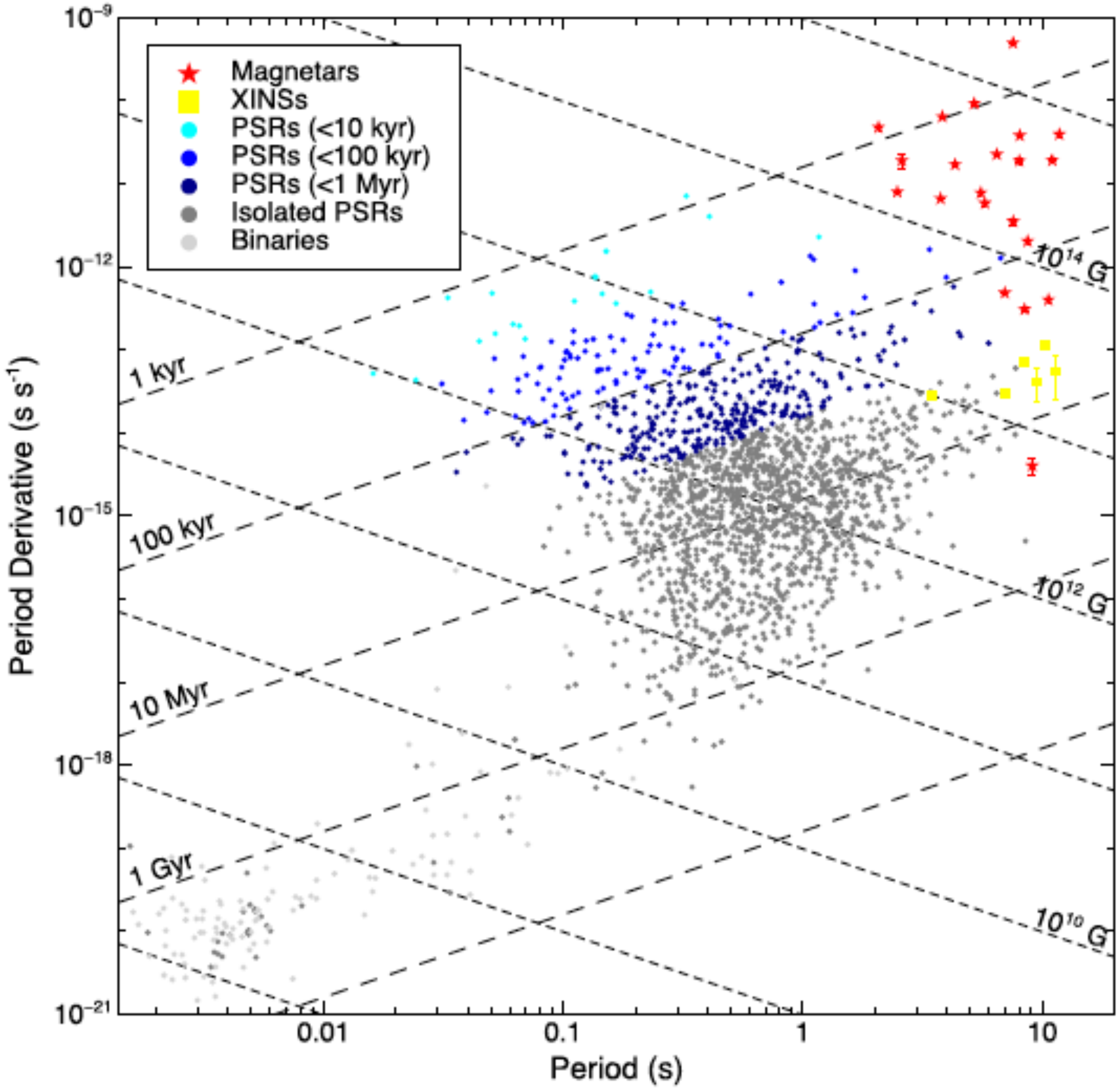


Kuiper et al 2006



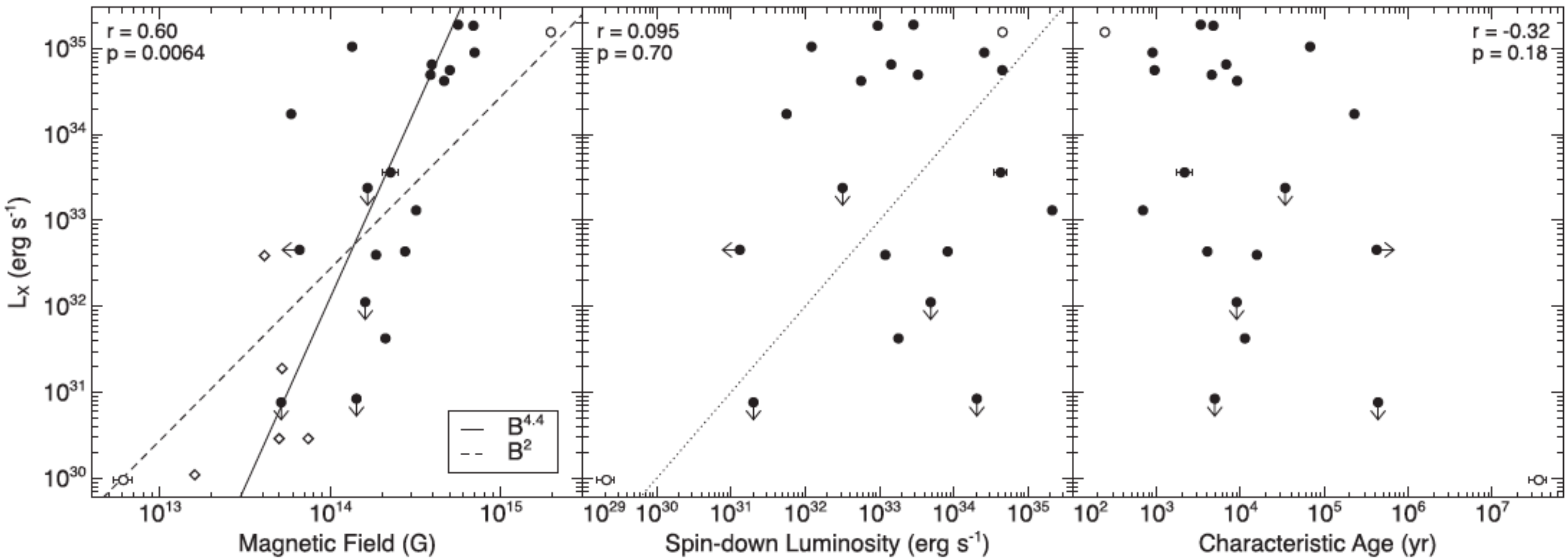
Hurley 2008

Magnetar p-pdot Diagram



Olausen & Kaspi, ApJ 2014

Quiescent properties
Correlations

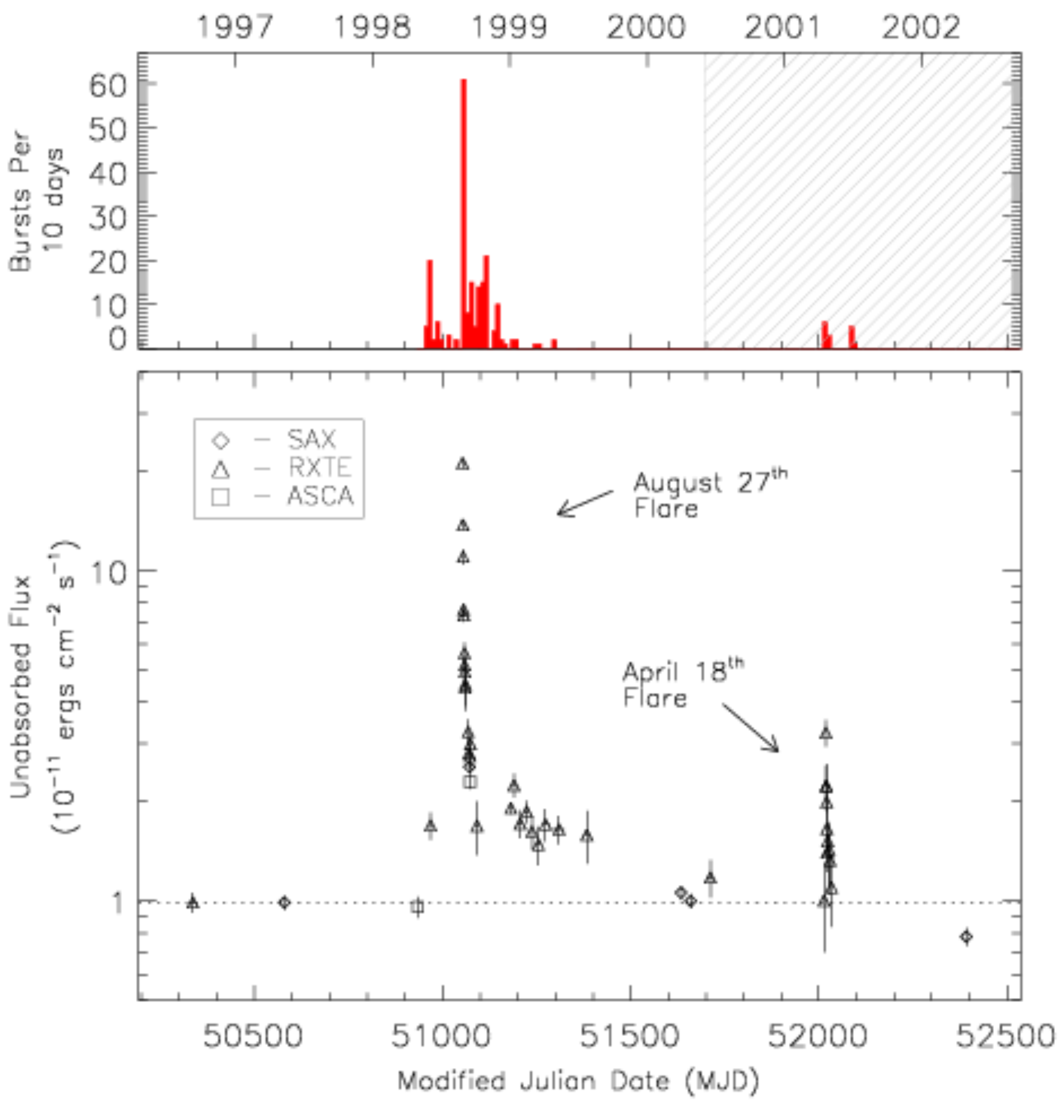


Olausen & Kaspi, ApJ 2014

Active Emission Properties: BURSTS

Collazzi et al 2014

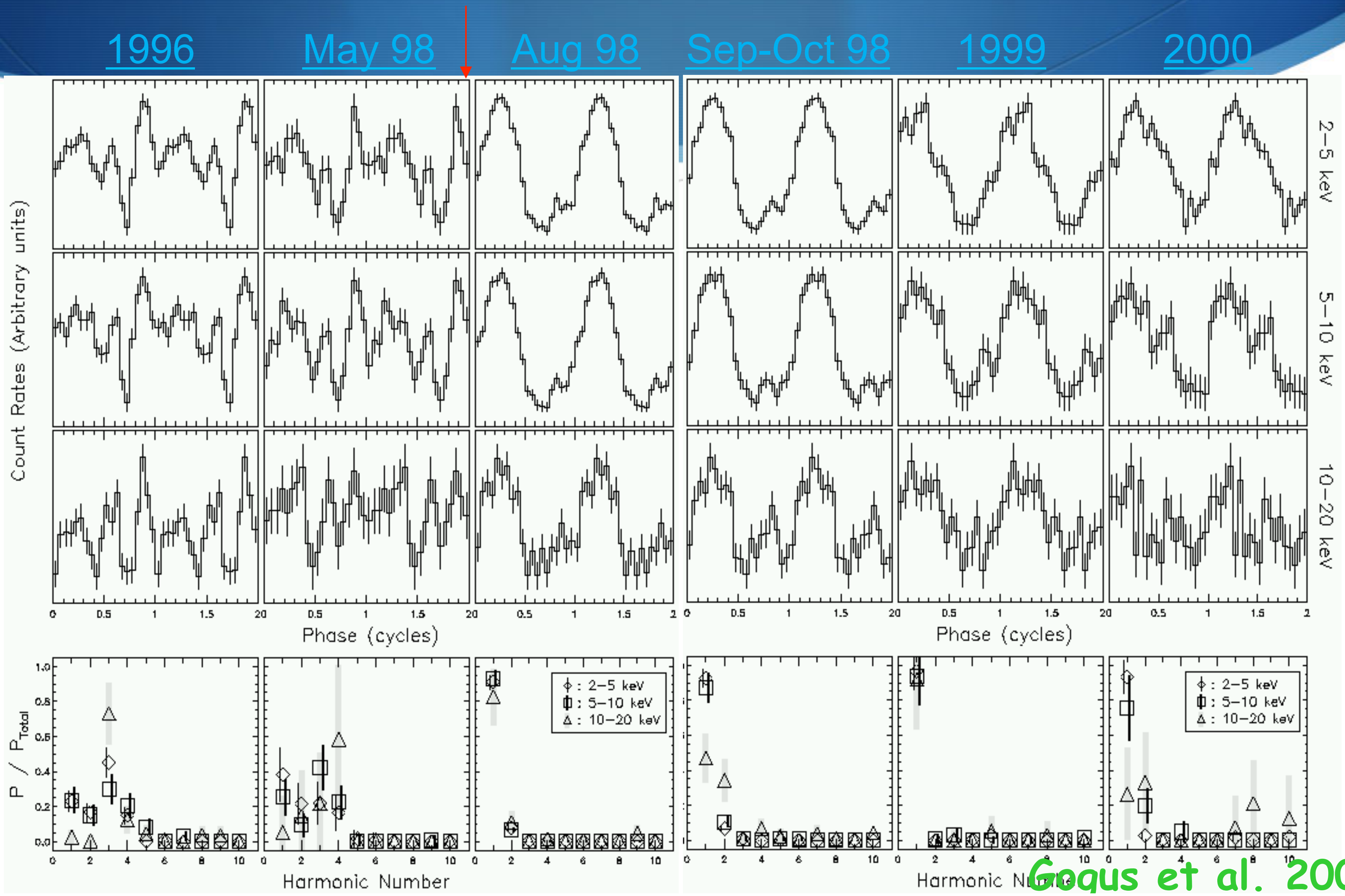
Outburst effect in the persistent flux



SGR 1900+14

Woods et al. 2002

Outburst effect in the pulse profile

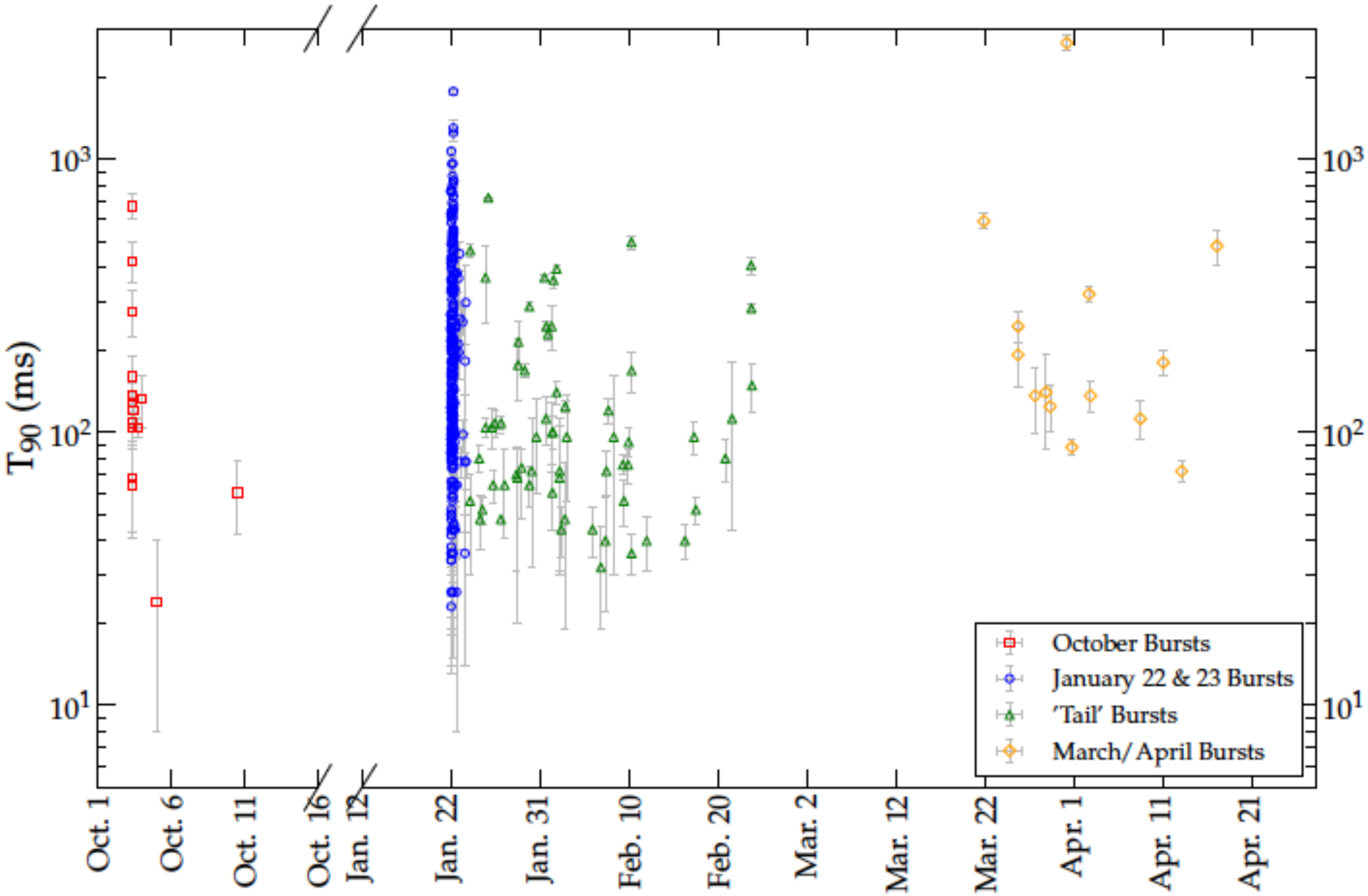


Gogus et al. 2002

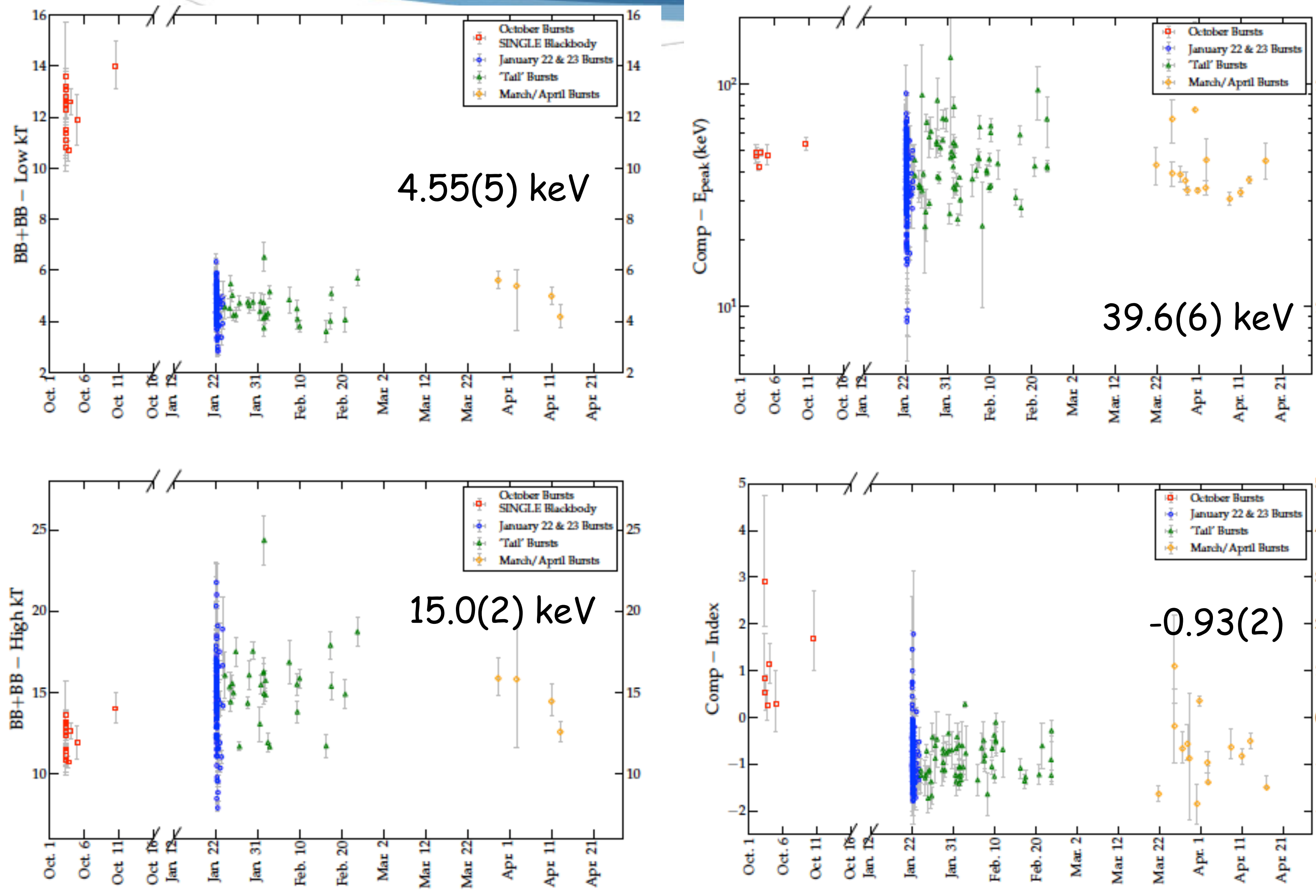
SGR J1550-5418 (AXP 1E1547.0-5408)

- $P = 2.069s$
- $\dot{P} = 2.318 \times 10^{-11}$ s/s and $B = 2.2 \times 10^{14}$ G
- Near IR detection, Ks = 18.5±0.3
- GBM triggered on 132 events from the source in three episodes; 2008 October, 2009 January & March. Once more on 2013 June.
- Only three other sources have exhibited in the past such "burst storms": SGR 1806-20, SGR 1900+14, SGR 1627-41
- T_{90} burst duration = 155 (10) ms for 353 (unsaturated) bursts

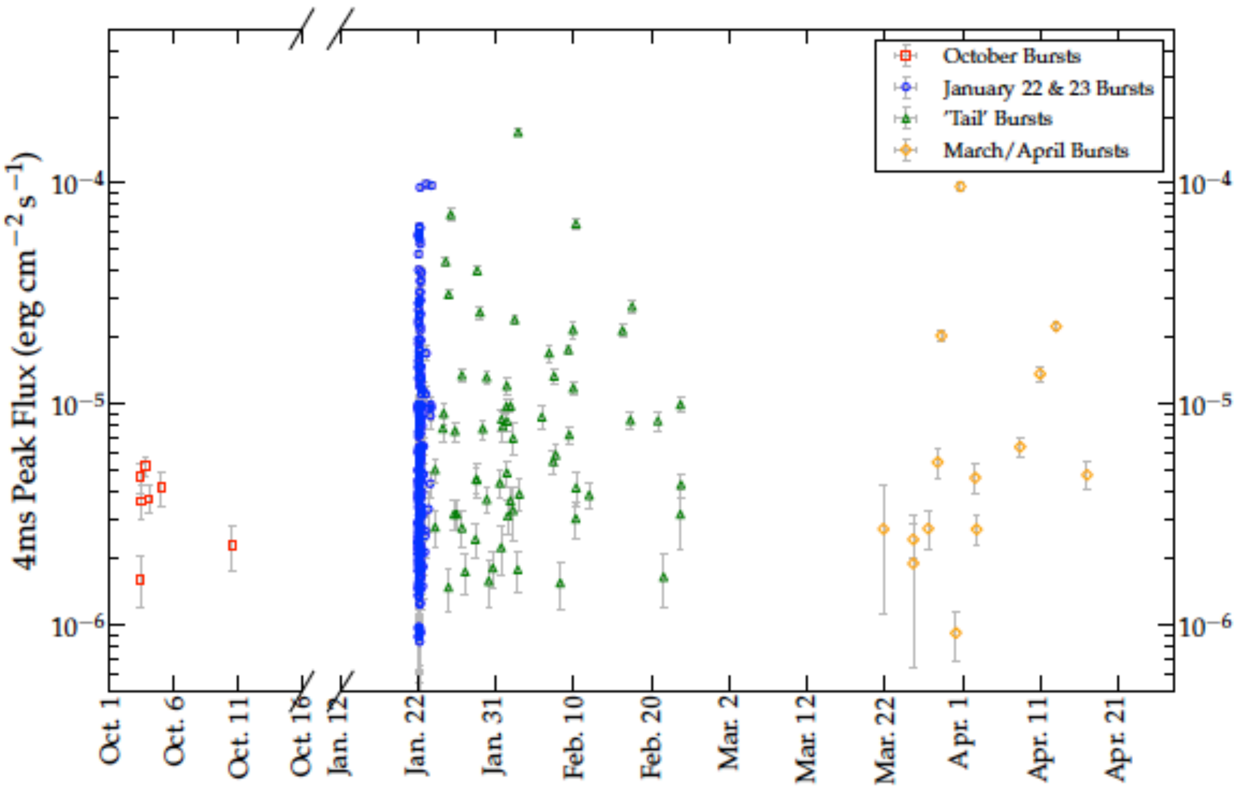
SGR J1550 – 5418: Temporal

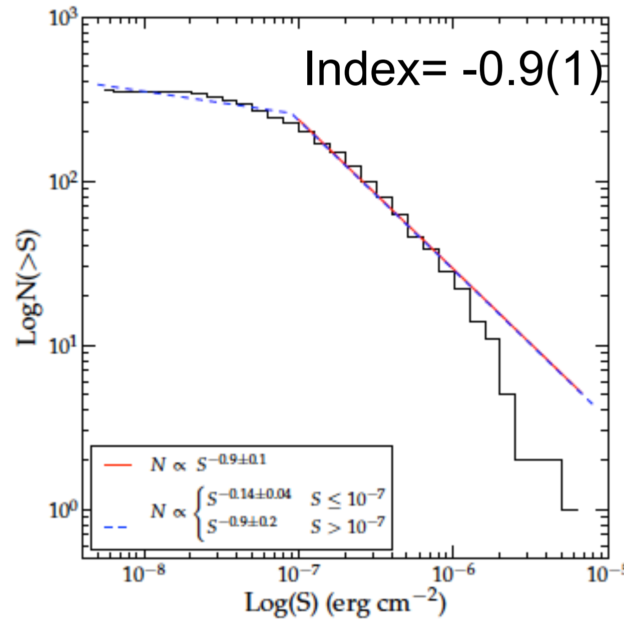


SGR J1550 - 5418: Spectral

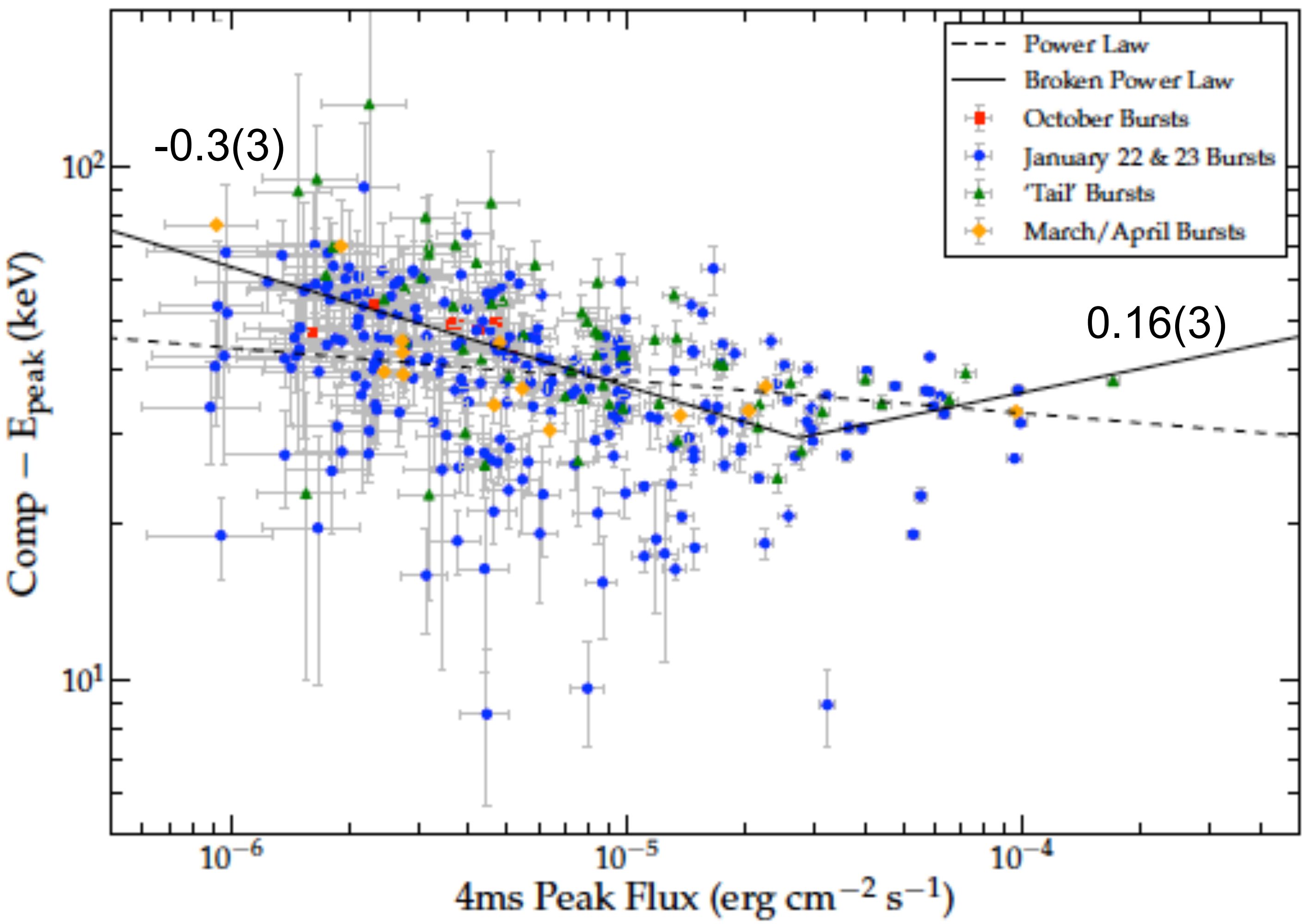


SGR J1550 – 5418: Spectral



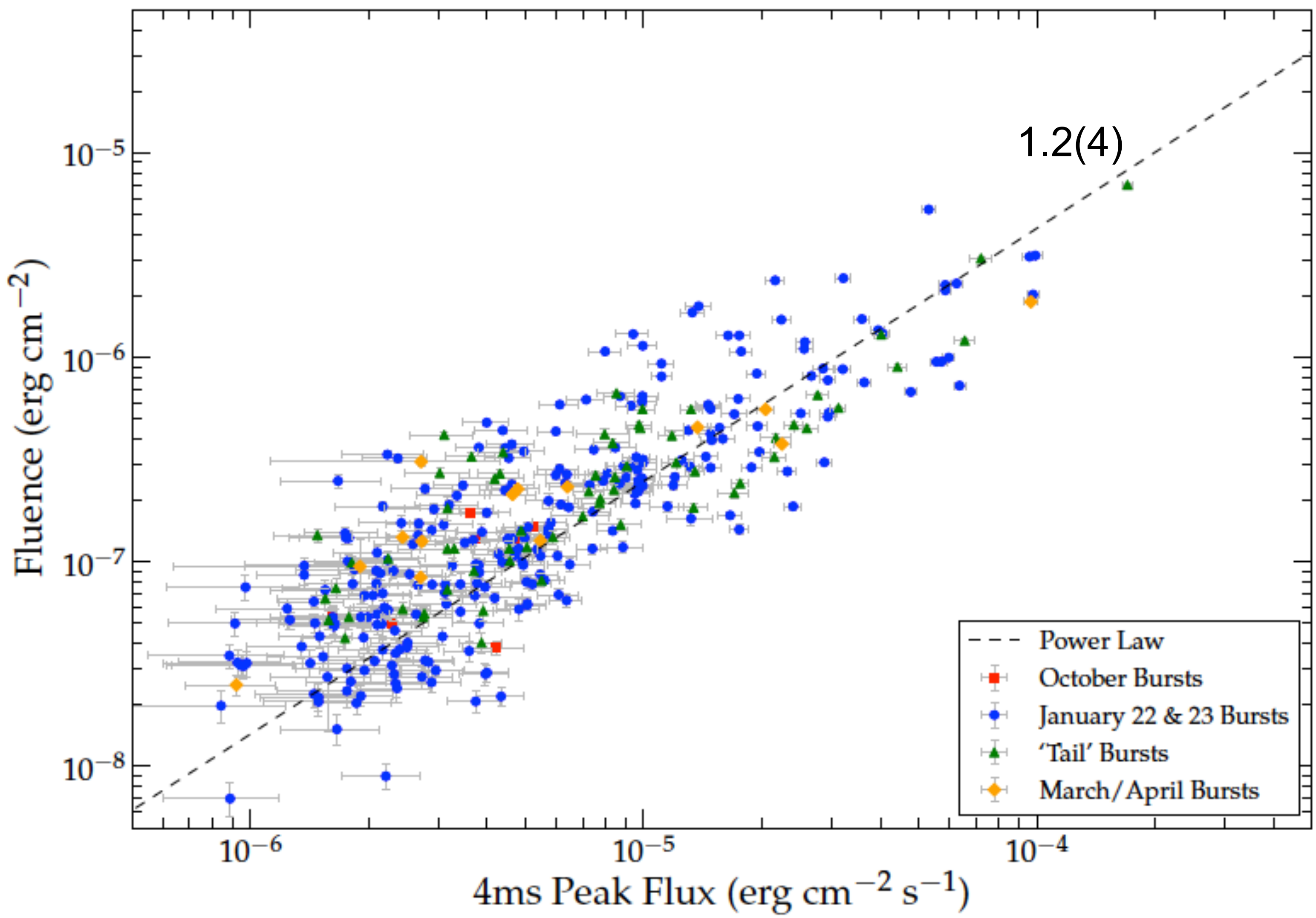


SGR J1550 – 5418: Correlations

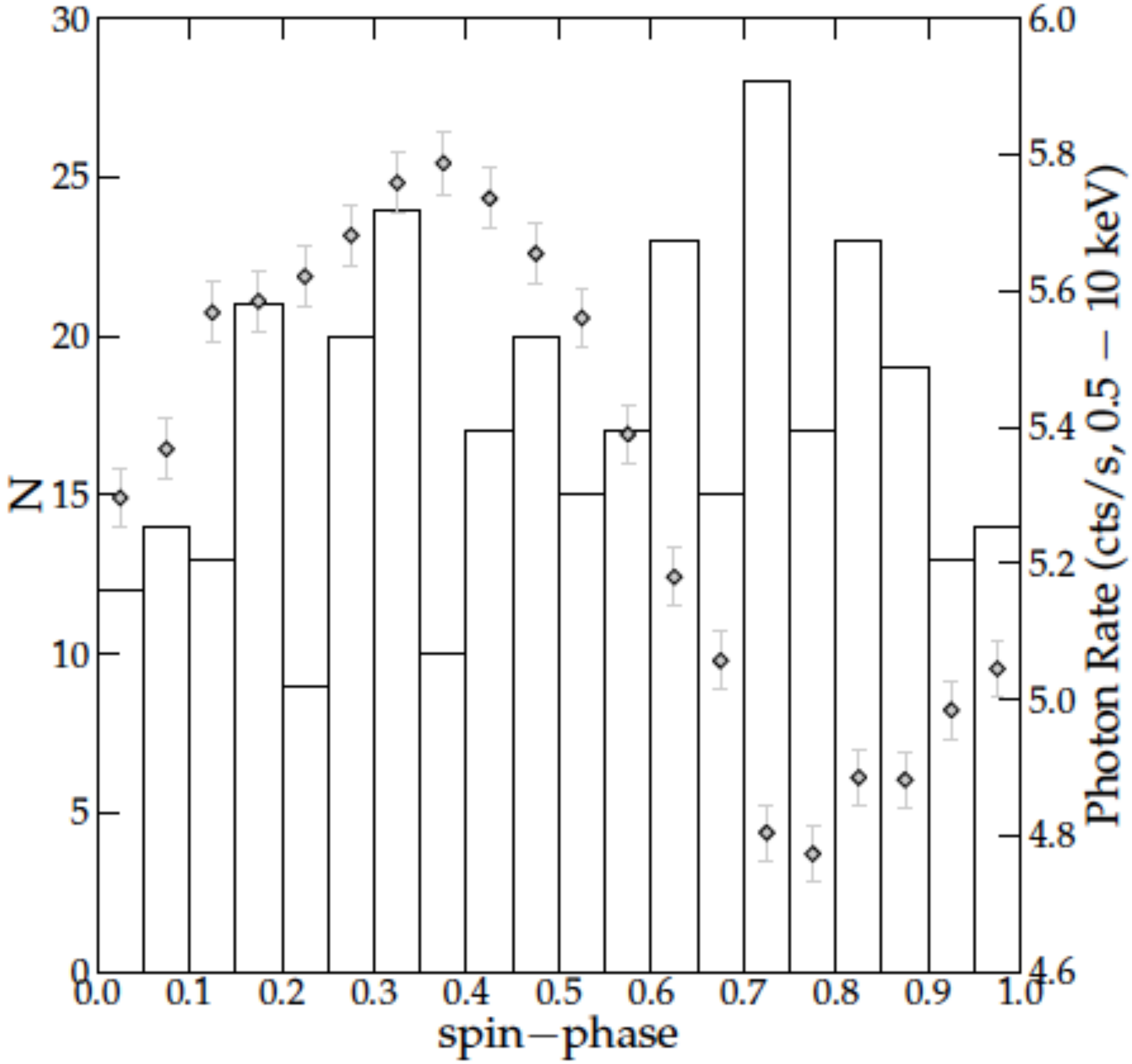


- GBM data → E_{peak} as hardness indicator. More accurate than hardness ratios
- Large flux/ fluence range: not a simple (anti-)correlation?
- Similar to SGRs J0501+4516, 1806-20, 1900+14

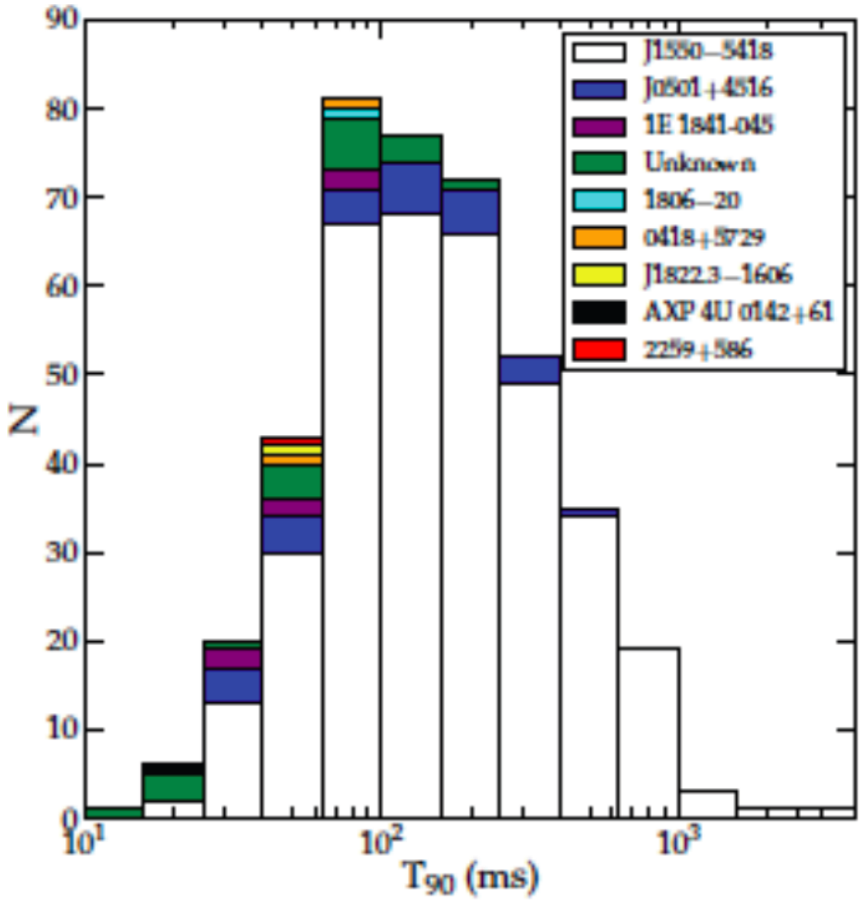
SGR J1550 - 5418: Correlations

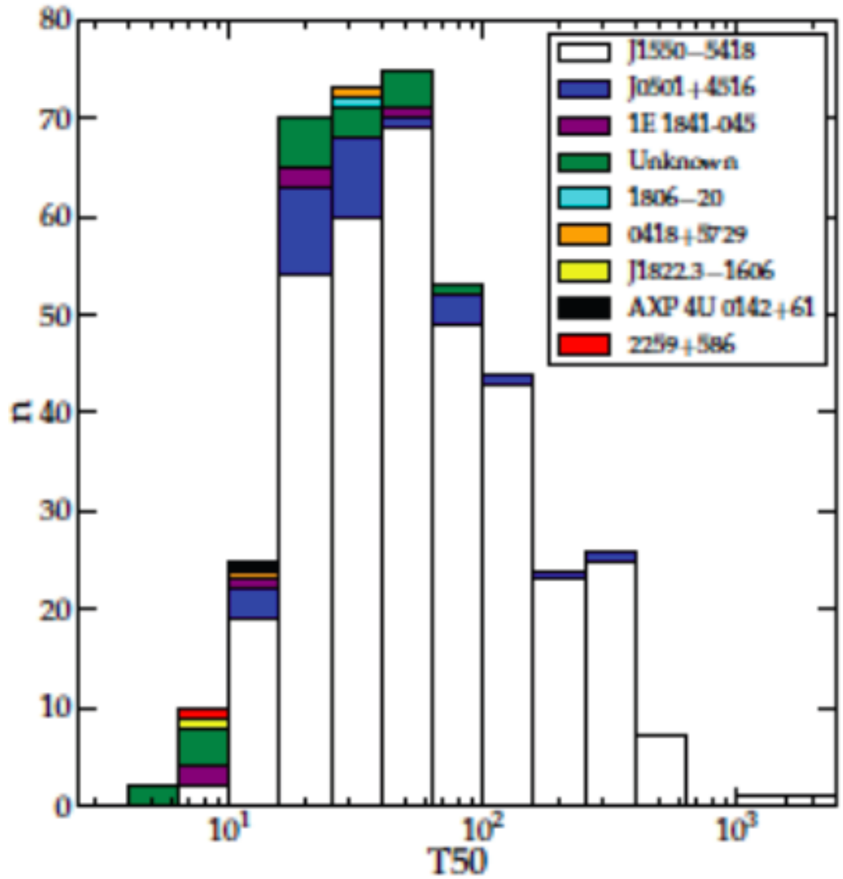


SGR J1550 – 5418: phase correlations



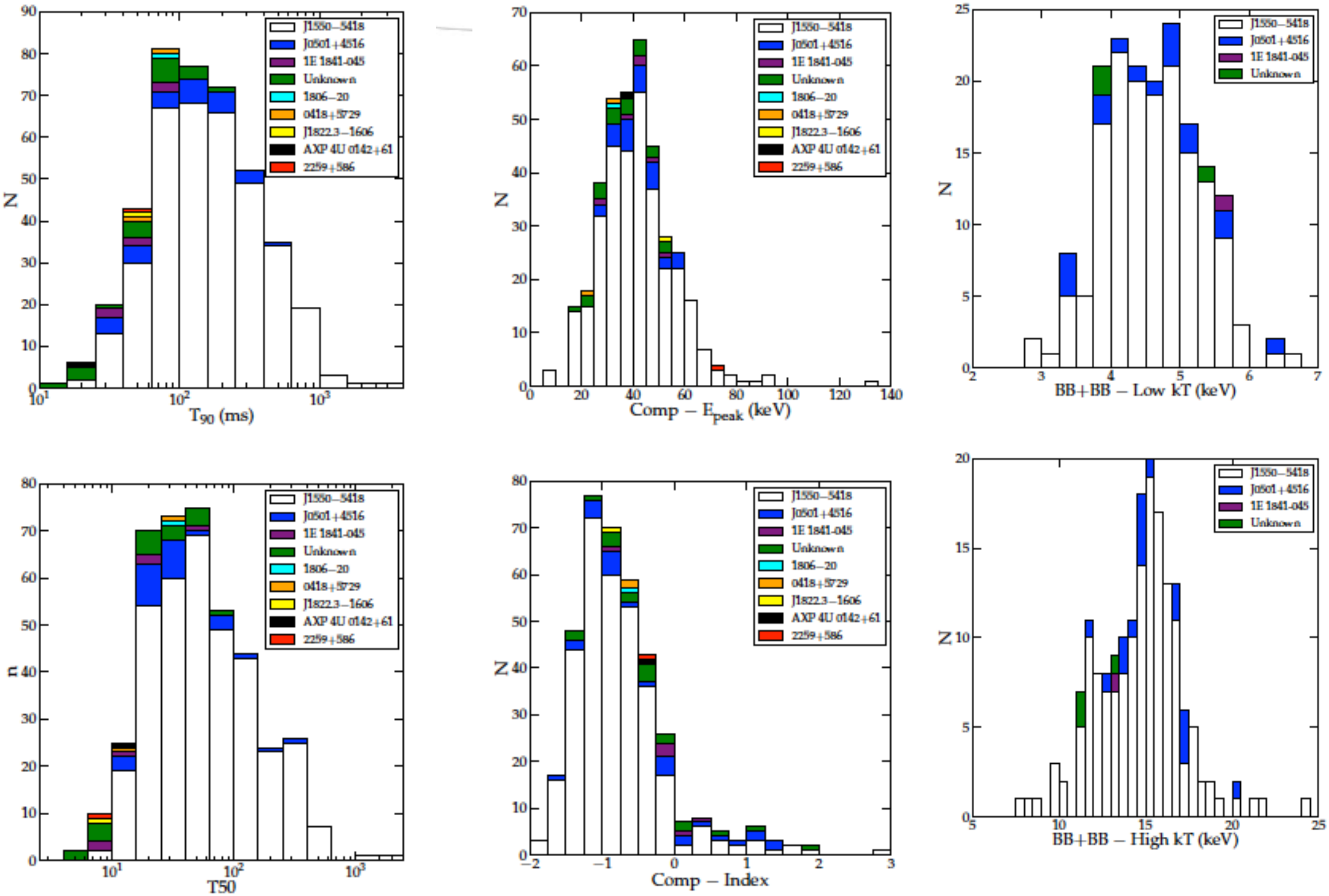
All triggers: temporal properties





Unknown event avg T_{90} = 61 ms (known avg ~100 ms)

All triggers: comparative properties



BURST ENERGETICS

1550-5418

Fluence: 7×10^{-9}–1×10^{-5} erg/cm^2

E=(2×10^{37}-3×10^{40}) d_5 erg

Flux: 8×10^{-7}-2×10^{-4} erg/cm^{2}s

L: 5×10^{38} -1×10^{41} erg/s

Total Energy Release: $6.6\times10^{41} d_5$ erg (8-200 keV)

1806-20: 3.0×10^{36}-4.9×10^{39}erg

1900+14: 7×10^{35}-2×10^{39}erg

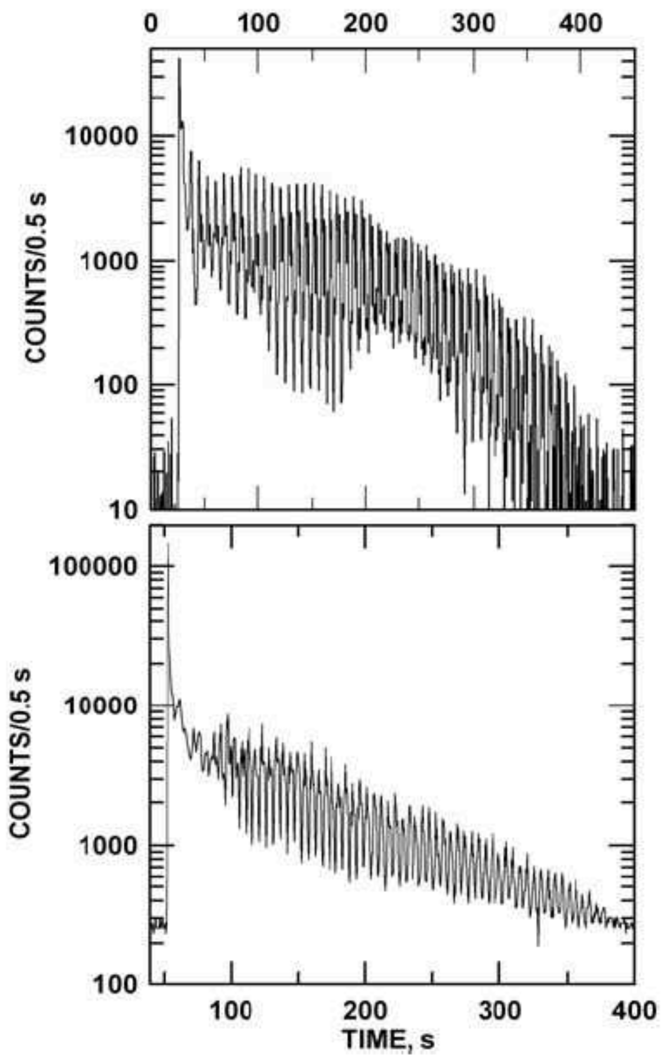
1627-41: 10^{38}-10^{41} erg

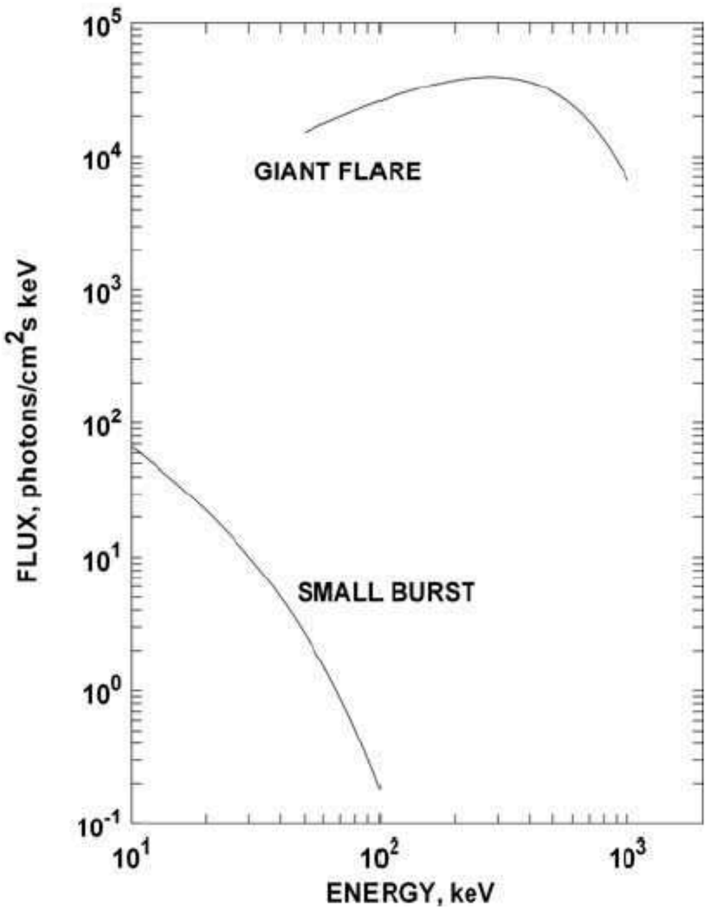
0501+4516: 2×10^{37}-1×10^{40}erg

1E2259+586: 5×10^{34}-7×10^{36}erg

Magnetar Giant Flares

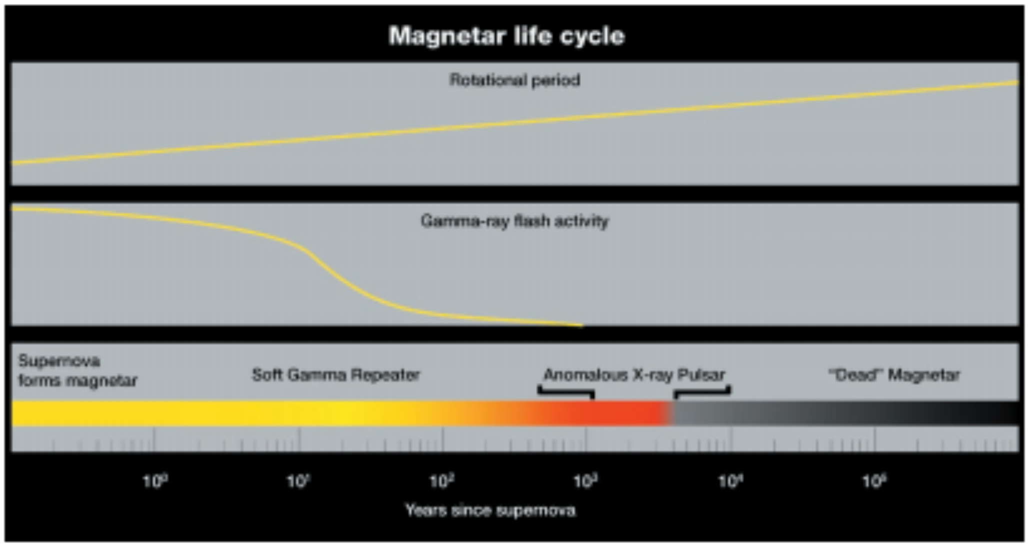
E up to 3×10^{46} erg
1 erg cm^{-2} at Earth



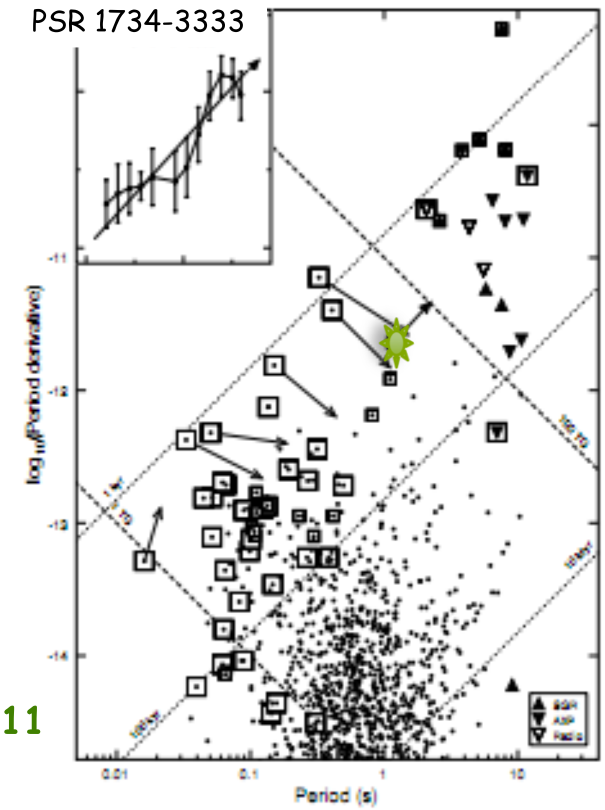


Hurley 2008

Evolutionary links?



Kouveliotou 1999



Espinoza etal 2011

What is the evolutionary link between different types of sources?

Rotation powered PSRs -> SGRs -> AXPs -> DINS

(Kouveliotou 1999, Perna & Pons 2011, Turolla etal 2011, Espinoza etal 2011)

Fermi MAGNETAR Facts

1. Since the Fermi launch, GBM has detected bursts from 8 sources: one third of the total population in five years!
2. The GBM magnetar burst spectra provide the first evidence for an unusual hardness E_{peak} – flux relationship.
3. Evidence for higher energetic content in SGR bursts than in AXP bursts.
4. Upper limits on the LAT emission detection only.

What Next?

The next five years of Magnetar observations:

- Population studies of magnetars
- Understand the links between PSRs – Magnetars – DINS
- Systematic searches for seismic vibrations in magnetar bursts- independent B-field measurement
- Giant flare detection becomes a strong possibility (for a rate of 1/ source/10yrs, we expect one in the next three years – last was in 2004)
- Confirm pulsed emission breaks >100 keV will constrain E_{max} of particles and localization of emission

Overarching theoretical issues:

- Localize the burst energy injection possibly on or near the NS surface to determine the injection mechanism
- Detection of gravitational waves from magnetar Giant Flares
- Determination of the magnetic Eddington limit

Synergy with new observatories:

NuSTAR, LIGO, LOFAR, AstroSAT, SVOM

Serendipitous Discoveries:

Always welcome!

The GBM Magnetar Team

- C. Kouveliotou (NASA/MSFC, USA), G. Younes (USRA, USA), S. Guiriec (UoMD, USA), A. von Kienlin (MPE, Germany)
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- A. Watts, A. van der Horst, D. Huppenkothen, M. van der Klis, R. Wijers, T. van Putten (U. of Amsterdam, The Netherlands)
- J. Granot (The Open University, Israel)
- J. McEnery, N. Gehrels, A. Harding (NASA/GSFC, USA)

SGR J1550 – 5418: phase correlations